The true redshift distribution of Pre-SWIFT gamma-ray bursts

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Abstract. SWIFT bursts appear to be more distant than previous bursts. We present the Boer & Gendre relation that link redshift and afterglow luminosities. Taking advantage of the XMM-Newton, Chandra and BeppoSAX catalogs, and using this relation, we have investigated the redshift distribution of GRBs. We find that XMM burst sources with unknown redshift appear to be more distant than those with a known redshift. We propose that this effect may be due to a selection effect of pre-SWIFT optical observations.

INTRODUCTION

The observations of long Gamma-Ray Burst (GRB) afterglows allowed the emergence of the fireball model [1, 2, 3]. In this model an isotropic blast wave propagates into a surrounding uniform interstellar medium (ISM). Two refinements were made: first, the isotropic assumption was relaxed. This model was called the "jet model" [4]. Second, observations showed that long GRBs may be linked with the explosion of a massive star (hypernova, [5]). In such a case, the surrounding medium is not uniform [6] because of the wind from the progenitor of the GRB. This model is referred as the "wind model" [7, 3, 6].

As GRBs are distant events, one may use them for cosmological studies. They may trace the star formation history and constrain the cosmological parameters. With distant bursts, such as GRB 050904 (z=6.29, [8]), observed by SWIFT and TAROT [9, 10], one can also observe the death of the first stars and the re-ionization period. Recently, it appears that SWIFT bursts were observed to be more distant than previous bursts [11]. This is rather obvious when looking at Fig. 1, which displays the cumulative distribution of redshifts derived from pre-SWIFT observations versus those measured from SWIFT detections.

We reported earlier that GRB X-ray afterglows with known redshifts have a bimodal luminosity evolution : the faintest GRB afterglows appear to decay more slowly than the brighter ones [12]. Bright and faint X-ray afterglows are separated by one order of magnitude in flux one day after the burst.We can use this relation as a redshift estimator. From the distances we compute, we are able to explain the observed difference in the cumulative distributions of redshift presented in Fig. 1, as a selection bias.
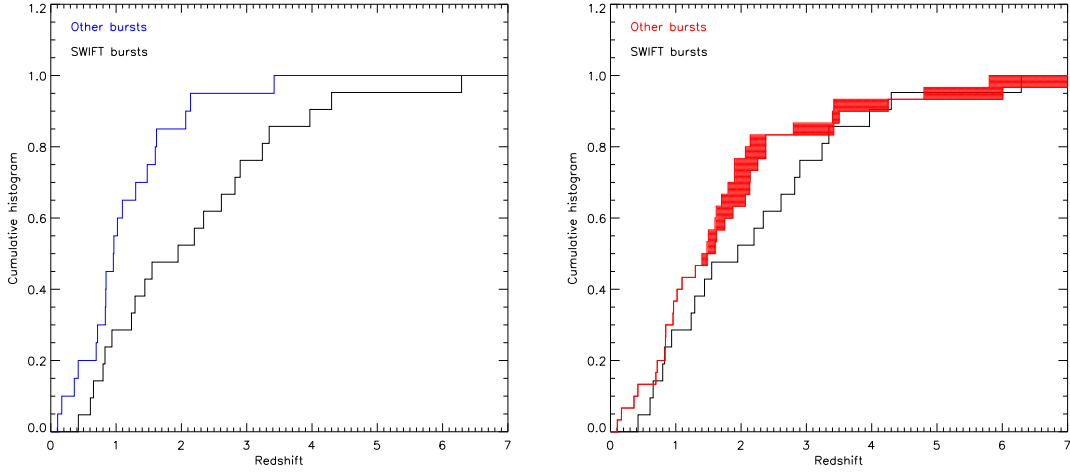
FIGURE 1. The redshift distributions of pre-SWIFT (color line) and SWIFT (black line) bursts. Left : using only bursts with a redshift measured by optical studies. Right : using bursts with a redshift measured either by an optical study or by the use of the Boër & Gendre relation. The shaded area represents the uncertainties of the redshift distribution.

TABLE 1. Bursts used to derive the Boër & Gendre relation. We indicate for each burst its redshift and the satellite that observed the X-ray afterglow.

Burst name	Redshift	X-ray satellite	Burst name	Redshift	X-ray satellite
GRB 970228	0.695	BeppoSAX	GRB 011121	0.36	BeppoSAX
GRB 970508	0.835	BeppoSAX	GRB 011211	2.14	XMM-newton
GRB 971214	3.42	BeppoSAX	GRB 020405	0.69	Chandra
GRB 980425	0.0085	BeppoSAX	GRB 020813	1.25	Chandra
GRB 980613	1.096	BeppoSAX	GRB 021004	2.3	Chandra
GRB 980703	0.966	BeppoSAX	GRB 030226	1.98	Chandra
GRB 990123	1.60	BeppoSAX	GRB 030328	1.52	Chandra
GRB 990510	1.619	BeppoSAX	GRB 030329	0.168	XMM-Neton
GRB 991216	1.02	Chandra	GRB 031203	0.105	XMM-Newton
GRB 000210	0.846	BeppoSAX	GRB 050401	2.90	SWIFT
GRB 000214	0.42	BeppoSAX	GRB 050525A	0.606	SWIFT
GRB 000926	2.066	BeppoSAX	GRB 050904	6.29	SWIFT
GRB 010222	1.477	BeppoSAX	GRB 050908	3.344	SWIFT

THE BOËR & GENDRE RELATION

Derivation of the relation

Our sample is listed in Table 1. We used only GRBs with known redshifts that exhibit an X-ray afterglow observed either by BeppoSAX, XMM-Newton, Chandra or SWIFT. The detail of data analysis is presented in [13].

We have corrected the fluxes for distance, time dilation, and energy losses due to the
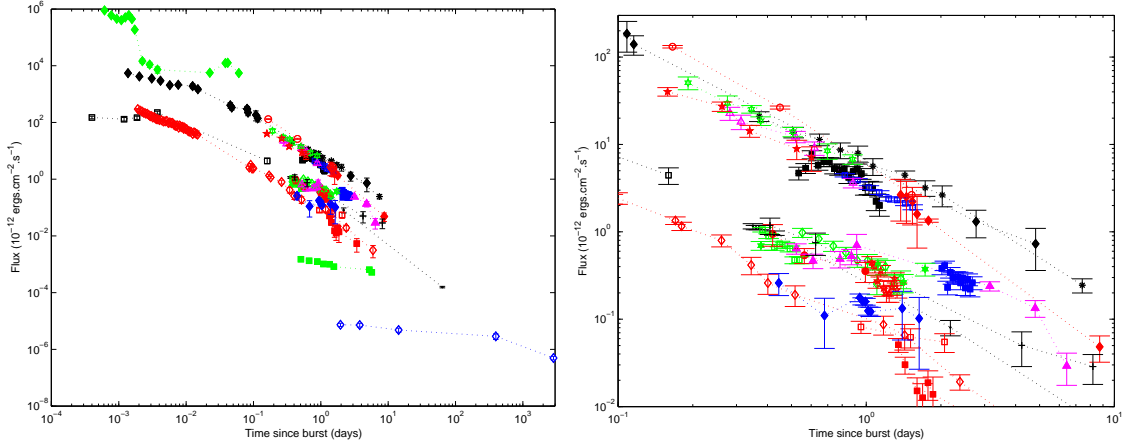
FIGURE 2. The Boër & Gendre relation made with 26 bursts. Left panel: full scale to show all bursts. Right panel: we display the same relation restricted to the time interval from 0.1 to 10 days after the GRB.

cosmological energy shift. To compute these corrections, we used a flat universe model, with an Ω_m value of 0.3. We normalized the flux to a common distance of z=1 rather than using the luminosity. We corrected the cosmological energy shift as in [14]. In order to reduce uncertainties, we did not correct for the time dilation effect by interpolating the flux as in [14]; instead, we computed the time of the measurement in the burst rest-frame. Finally, we restricted the light curves to the $2.0-10.0$ keV X-ray band, where the absorption is negligible. This allowed us to neglect any other corrections for absorption by the ISM. We do not take into account any beaming due to a possible jet.

The two groups reported in [12] are still present (see Fig. 2). All but two bursts lie in one of the two groups. The only exceptions are GRB 980425 and GRB 031203. In the following we call *group I* the set of GRB afterglows with the brightest luminosity, and *group II* the dimmer ones. The probability that a power law luminosity distribution (letting the index be a free parameter) represent the observed distribution is, at the maximum, 1.2×10^{-6} (index value : -1), thus the observed clustering in two groups is very significant.

We computed the mean decay index of the groups. We find $\delta = 1.6 \pm 0.2$ for *group I*. If we take into account all bursts of *group II*, we find $\delta = 1.5 \pm 0.9$. However, if we take into account only the bursts with a good decay constraint (hence ignoring GRB 011121 and GRB 030226), we get $\delta = 1.1 \pm 0.2$. Using a Kolmogorov-Smirnov test to check if this repartition is due to a single population of GRBs, we obtain a probability of 0.13 : this distribution of decay indexes may be due to only one population.

Validity of the relation as a distance estimator

Before using this relation as a distance estimator, one may check its validity.

1. It has been reported by [15] a weak clustering in two groups. This effect is probably due to the time dilatation correction computed by these authors: As noted above,
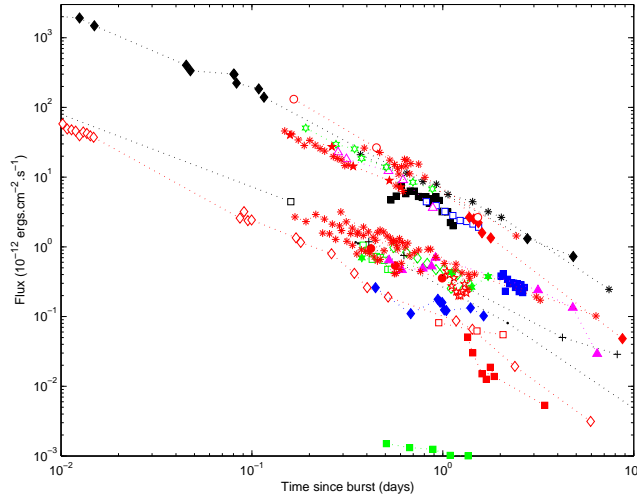
FIGURE 3. The rescaled bursts.

and also stated by [16], this correction needs to be computed without extrapolations (as done in [13]), otherwise the uncertainties on the decay index and on the mean flux level might broaden the true distribution.

2. Several discrepancies between SWIFT bursts and other bursts have been reported [17]. This might be the result of a selection effect. While this claim is still valid for the optical afterglows, [18] has shown that the X-ray afterglows of Beppo-SAX, XMM-Newton and SWIFT are similar. Thus, no selection effect can be objected if one uses X-ray afterglows, as we do.

3. Both nearby and distant bursts may be used to check the validity domain of the relation. At large distances (z>5) only one burst (GRB 050904) is present in our sample. It presents strong flaring activity [19, 20] which may make conclusions difficult to draw at first glance; however this burst agrees with the relation (see Fig. 2). At small distances (z<0.1), two bursts (GRB 980425 and GRB 031203) are present in the sample. As can be seen in Fig. 2, they do not follow the relation. These events are the only outliers we found, and this might be due to a distance effect : as a conservative hypothesis we prefer to restrict the validity of the Boër & gendre relation to redshifts larger than 0.5.

We emphasize that the bursts were sorted in each groups according only to their X-ray properties (the decay index), and that we did not use any redshift estimate. When the classification was ambiguous (e.g. for a decay index of 1.4)we systematically privileged the group that gave the lowest redshift value, i.e. disfavoring high redshifts (where we want to check the relation).

THE REDSHIFT DISTRIBUTION OF PRE-SWIFT BURSTS

We used the Boër & Gendre relation to derive the distance of the bursts listed in Table 2. As one may note, only one burst does not reach the lower threshold, and thus we do

TABLE 2.   Redshift estimates derived from the Boër & Gendre relation

GRB name	Spectral index	Observing satellite	Redshift estimate
GRB 001025A	1.8	XMM-Newton	5.8
GRB 020322	1.1	XMM-Newton	1.8
GRB 040106	0.49	XMM-Newton	3.4
GRB 040223	1.6	XMM-Newton	1.9
GRB 040827	1.3	XMM-Newton	1.9
GRB 980329	1.44	BeppoSAX	1.5
GRB 980519	2.43	BeppoSAX	4.8
GRB 990704	1.68	BeppoSAX	1.4
GRB 990806	1.31	BeppoSAX	1.7
GRB 001109	1.29	BeppoSAX	2.8
GRB 020410	1.3	BeppoSAX	0.5

not consider it in the following discussion. The mean redshift for SWIFT bursts is 2.7, while the mean pre-SWIFT mean redshift was 1.2. We took into account the bursts from table 2 to recomputed the redshift distributions; the result is displayed on the right panel of Fig. 1. As it can be seen, with this method the pre-SWIFT and SWIFT distributions do agree both at low and high redshifts. The observed difference at intermediate redshift can be explained by a lack of SWIFT bursts at these distances, and is compatible with the expectation derived from Poisson counting statistics. We note also the interesting result of GRB 001025A. This burst was observed by XMM-Newton but its optical afterglow was never detected, and thus it was classified as dark burst [21]. With a calculated redshift of 5.8 ± 0.8, this can be easily explained by the Lyman alpha cutoff.

As stated above, there is a bias observed with the SWIFT optical afterglows : they appear fainter than the pre-SWIFT ones [17]. This has strong consequences on the distance estimation of the bursts. This estimate is based on spectroscopic observations of the optical afterglow which is detected mostly after an X-ray observation gave the precise position of the transient. Before SWIFT X-ray observations were made hours after the burst. Hence the optical follow-up occurred at least hours, or even days, after the event, when the optical transient had significantly faded. Thus the OT detection implied a bright source: they are not common as discovered by SWIFT. Because of the cosmological effects, a burst will have its flux decreasing with the distance if the afterglow spectral index is larger than 1 (as observed in most of the afterglows by [7, 16]) : bright bursts will be on average nearby, biasing the pre-SWIFT distribution against high redshifts. Since our analysis is unbiased in that sense, we do not see any difference in distance in the two samples.

CONCLUSIONS

We have presented the Boër & Gendre relation which links the X-ray afterglow luminosity and the GRB source distance. We use it to derive the distance of burst sources with unknown redshift. We observe significantly more distant bursts by using our method, than selecting them only on their optical properties. We show that the redshift distribution of GRB sources computed from the pre-SWIFT and SWIFT sample agree when

using the Boër and Gendre relation.

We infer that the difference previously reported is due to a selection bias due to the optical measurements of the redshift of pre-SWIFT bursts.

ACKNOWLEDGMENTS

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